PRODUCTION PLANNING AND INVENTORY CONTROL MODELLING IN A COMPOSITE TEXTILE MILL

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PRODUCTION PLANNING AND

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IN A COMPOSITE TEXTILE MILL

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CHAPTER I

INTRODUCTION

The aim of this thesis is to develop a mathematical model for production planning and inventory control in a typical composite textile mill. An attempt will be made to show how this planning technique may be used effectively to assist other functions such as marketing and scheduling in the textile production system.

Although much work has been carried out in the general area of production planning, little has been published specifically for the textile environment.

Purpose of the Research

The need for production planning arises out of the observation that many mills suffer losses, or fail to attain maximum possible profits because of improper planning of production and inventory at critical stages. Many times large amounts of capital are tied up in inventory at relatively less crucial points. Shortages which upset the entire production schedule and result in heavy losses, then occur at crucial stages. Sometimes production plans are drawn which are not feasible practically. There are a large number of products which every textile mill can manufacture using the same basic resources of raw material, men, and machines. Each of these may require varying amounts of these resources, thus the costs and also the unit profits are different for the different products. Since the resources are usually limited, the problem arises as to what products should be manufactured, in what quantity, and by what date. Production schedules depend on various factors such as demand, availability of resources, costs, selling price, and the company's marketing strategy. Considering all the factors simultaneously may result in a large number of feasible combinations of schedules. It is obviously impractical to try out each possibility in the mill. Through production planning it is possible to determine the plan that most profitably employs the company resources. This plan is based both on sales forecasts and the manufacturing constraints. Production planning ensures that the detailed plans generated to meet a production schedule are feasible and can be executed within the resources available. Also, production planning allows textile managers to make a thorough analysis in long-range planning of resources, as well as short-range changes that can be made on an existing production plan. The inprocess inventroy which depends on various factors as material demand, value of goods, risk of obsolescence, is very much a part of the entire production plan.

A major advantage of the techniques used for production planning is the use of sensitivity analysis. It provides the planning system with the capability to simulate the addition of new resources. This simulation helps to determine the effect on profitability of acquiring additonal resources. To help marketing strategy, alternative plans can be tried by changing the selling price of the product and keeping the demand pattern consistent. The most profitable plan can then be selected. The validity of the results will of course depend largely on the accuracy of sales forecasts. The effect on profitability by marginal changes in costs, resources can be studied very easily. Once the production plan is set up and is in the processing stage, it is possible to study the effect on profitability by the introduction of new products (variables) or resource limitations (constraints).

It is thus obvious that by the use of production planning, more options can be considered in greater detail than would ever have been feasible with a manual system.

Method of Procedure

In the work to follow, a general production planning model will be set up for a composite textile mill which can be used for any number of products and planning periods using both normal and overtime production facilities. It will be solved for a three-products system with two periods. The Flex linear programming program on the ISYE Library (see Appendix III) has been modified for use in this case. The data used for costs, production capacities, and material requirements were taken from Campbell's[1] book on costing. The limitations and suggestions for further work on the model will be discussed in the later part of this thesis.

CHAPTER II

REVIEW OF PRODUCTION PLANNING MODELS

Production planning as a management tool is being used in a few textile companies. Most companies are not aware of its applications to other areas such as marketing and scheduling.

The highly competitive and complex textile environment is very different from that of most other industries. The large fluctuations in demand, raw material costs, and raw material availability makes planning all the more difficult. Every company has to plan ahead regarding production schedules and sales. Uncertainity in the market makes it important to have a technique whereby it is possible to simulate in advance the effect of alternative production plans on company's profitability.

The concept of production planning may be well understood as given by Bock.(2) He states that

> Production Planning involves setting production levels for several periods in the future and assigning general responsibility to provide a data for making decisions on the size and composition of the labor force, capital equipment and plant additions, and planned inventory levels. The ability to meet demand levels generated by possible alternative sales programs is also a function of production planning.

Production plans are used for many different purposes. One example is the use of a production plan to help determine the amount of new capital equipment to be purchased in the future. In this instance a plan covering the next five, eight, or even ten years would be required and would indicate the production job to be done and the capital equipment necessary to accomplish this job.

At the same time that a production plan covering the next several years is necessary, another plan covering a much shorter time period might also be required. This plan might cover only the next few months and might be used to set aggregate production rates to meet forecasted demand and planned future inventory levels.

Production scheduling typically covers a much shorter period than production planning. Production schedules determine how production requirements in the next several weeks will be assigned to specific departments, processes, machines, and operators in order to meet real deadline imposed by the sales department and desired inventory levels.

Mathematical Concepts of Production Planning

The mathematical concepts of production planning may be well understood by the formulation of a very simple model. Let

x_i = quantity of product i, i = 1,2, ..., n, produced in the period

b_k = amount of resource k, k = 1,2, ..., k, available during the period

a_{ik} = number of units of resource k required to produce one unit of product i

V_i = maximum sales potential of product i in the period

L_i = required minimum production level of product i in the period

r_i = revenue, net of variable selling expense, from selling one unit of product i

C_i = unit variable cost of producing a unit of product i.

We assume that $(r_i - C_i)x_i$ is the contribution to overhead and profit resulting from the production and sale of x_i units of product i, where we suppose that all production of product i up to V_i units can be sold in the period. Furthermore we assume that production of x_i units of product i will use up $a_{ik}\, x_i$ units of resource k. Our objective is to choose x_1, x_2 ..., x_n such that it maximizes our profit. Mathematically,

$$\text{Max} \sum_{i=1}^{n} (r_i - C_i)x_i$$

subject to

$$\sum_{i=1}^{n} a_{ik}\, x_i \leq b_k \qquad (k = 1,2,3, \ldots, K)$$

$$x_i \leq V_i \qquad (i = 1,2, \ldots, n)$$

$$x_i \geq L_i \qquad (L_i \geq 0,\ i = 1,2, \ldots, n)$$

Production Process of a Textile Mill

In a textile mill, the flow of material (production-line) from the raw material stage to the greige cloth may be as shown in Figure 1.

It has been observed in most of the cases that main production bottlenecks are the weaving and spinning stages. It can usually be assumed that the requirements for any production possible in spinning can be met at the earlier stages.

The production process in a mill follows a continuous line. Generally speaking any single plan of a textile mill will process material for only one particular range of yarn counts. Counts may be either coarse, medium, or fine. This restriction is usually found

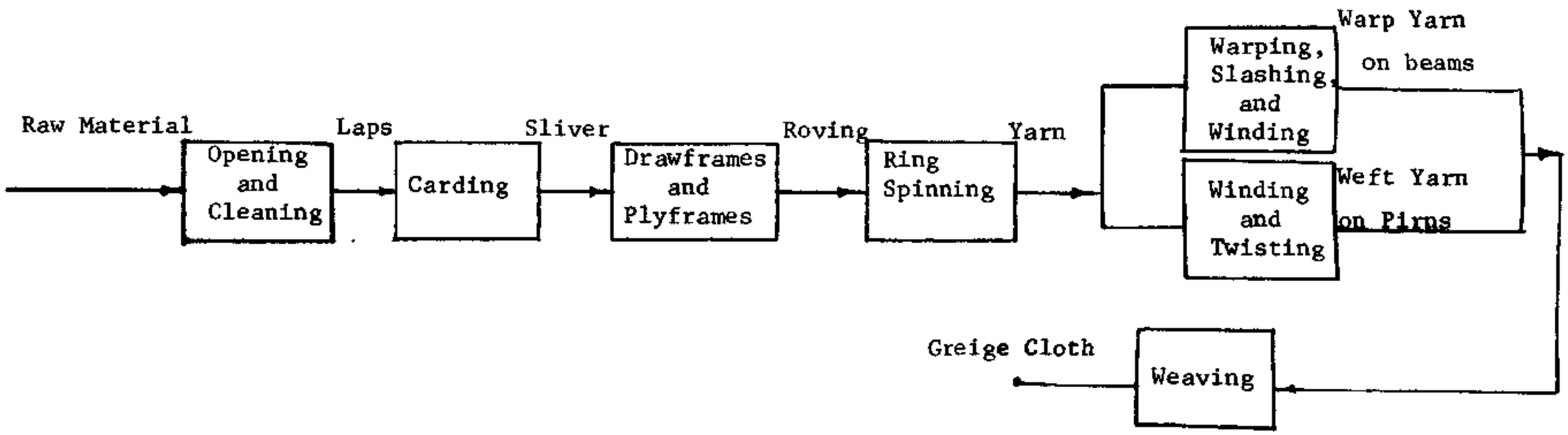

Figure 1. Production Line for a Typical Textile Mill.

because the setup costs in terms of time required to change the machine settings is very high and becomes uneconomical. For example, the number of opening and cleaning points may have to be changed depending upon the staple length of cotton fibers being used. Finer variety of cotton can tolerate less beating, whereas coarser varieties require harsher beating. Within a range of yarn counts, there is practically no difference in the speeds and drafts at carding and drawing stages. The weights of lap produced at the picker and the sliver at carding and drawing is the same. Thus it is reasonable to assume that the material (sliver) to be used at the roving stage is essentially the same in all respects. Hence, the production rates before that (roving) stage are same for all end products. Thus the raw material availability constraint is in effect the amount of sliver which may be available for production. If we assume that the production capacity to the drawing stage is sufficient to cover any production requirements which might be possible in spinning or weaving, then the constraint on production capacity before roving becomes redundant. This situation has in fact been found to be true in most of the textile industries.

At the roving stage, depending on the count of yarn to be spun, there may be some changes in the twist level and the hank of roving to be produced. These changes will affect the production rate. At the ring spinning, there is a marked change in production rate for different counts of yarn being spun. Moreover, the warp and weft (which go into the manufacture of final fabric) will vary in the degree of twist level. The term production rate being used refers to the weight/unit time of the material being produced. The machine speeds for different yarn counts remain the same. The speeds for spooling, warping, and warp-drawing remain the same. If a sizing operation is involved, the weight of size in the final cloth should be calculated separately (based on the size pick-up). Such factors as design (weave pattern), cover factor, and width of cloth may have different amounts of material (yarn) going into the same length of the different fabrics. Thus in affect the amount of raw material being consumed varies. Since fabrics are always sold in terms of length, the manufacturing costs and hence the revenue per unit length for different cloths will be different. In computing the data (Appendices I and II) required for production rates, material consumed (for all processes) it is necessary that proper adjustments be made for waste levels, efficiency of the operation, machine downtime, and piecing uptime required for various operations. In a textile mill, thousands of styles of cloth can be woven on the same type of looms; each utilizing the same resources, but in varying proportions. There is also the possibility of buying and selling yarn (if there is less or excess of production capacity respectively). Overtime can be used if desired and found economical.

Thus, to determine the optimal production level for each of the possible products, we are faced with a product mix problem involving multiple stages. This can be solved easily using production planning techniques.

Review of Mathematical Production Planning Models

Production planning for a general product mix problem has been dealt with by Johnson and Montgomery[3] in their book on Operations

Research in Production Planning, Scheduling and Inventory Control. They define a product mix decision as one in which the objective is to utilize limited resources to maximize the net value of the output from the production facilities. Production and sale of a given quantity of a product results in a certain contribution to overhead and profit (that is, the difference between variable sales revenue and variable production costs) and uses up certain resources such as materials, labor, machine time at various production centers, etc. The problem is to find the production program that maximizes the total contribution to profit and overhead during the period, subject to constraints imposed by resource limitations and considering customer orders already in hand and potential sales (forecasts).

The main features of a product mix problem are:

1. Maximization of contributions to profit and overhead.
2. Constraints resulting from resource limitations.
3. Bound constraints on planned production.

The problem is of a dynamic nature since production is planned over a future interval of time called the planning horizon, during which the rate of demand for the product varies. The time interval is divided into periods, and the planning problem is to establish a production rate for each period in the planning horizon.

Some of the alternatives available with the management to meet a fluctuating demand are:

1. Build inventories during periods of slack demand in anticipation of higher demand rates later in the planning interval.

2. Carry back orders or tolerate lost sales during periods of

peak demand.

3. Use overtime in peak periods or undertime in slack periods to vary output while holding work force and facilities constant.

4. Use subcontracting in peak periods.

5. Vary capacity by changing the size of the work force through hiring and firing.

6. Vary capacity through changes in plant and equipment. This is done only for long-range planning.

The decision regarding what strategy is to be applied is based on a proper tradeoff between the following types of costs:

1. Procurement costs for products purchased from outside sources.

2. Production costs.

3. Inventory holding costs.

4. Costs of increasing and decreasing work force levels.

5. Shortage losses associated with back orders and lost sales.

6. Costs of deviating from normal capacity through use of overtime or undertime.

7. Cost of changing production rates.

In order that this problem may be solved using linear programming, it is necessary that all the costs be linear functions of the variables defining the production program. Also, all the constraints should be linear.

A mathematical model which may be modified for a textile industry was given by Johnson[(3)] in a general form. In this situation, no back orders were permitted; the costs associated with changes in production rates or work-force level were also not considered. Instead of having a fixed production requirements based on demand for each product, it was desired to find the most profitable production program over the planning horizon. In other words, the quantity of goods to be sold in any period was treated as a decision variable. The first stage consists of a spinning plant manufacturing a number of different types of yarn, and the second stage contains weaving plants that use the yarns in producing several styles of woven cloth. There are several processes (routings) by which each yarn type can be produced. These routings differ in the combination of machine groups used in production of the yarn. A machine group may be defined as a set of identical machines at the same location. Similarly alternate routings exist for manufacture of a cloth style.

In the formulation of the model, the following variables are used:

x_{ijt} = number of units of (semifinished) product i produced by routing j at stage 1 in period t

Y_{pgt} = number of units of (finished) product p produced by routing g at stage 2 in period t. ($p = 1,2, \ldots, n_2$; $g = 1,2, \ldots, Q_p$)

S_{pt} = planned sales of product p in period t

I_{1it} = inventory of product i at stage 1 at the end of period t

I_{2pt} = inventory of product p at stage 2 at the end of period t

R_{pt} = unit variable revenue from the sale of product p in period t

C_{1ijt} = cost to produce a unit of semifinished product i by process j at stage 1 in period t

C_{2pgt} = cost to produce a unit of product p by process g at stage 2 in period t

h_{1it} = cost to carry a unit of semifinished product i in inventory at stage 1 from period t to t + 1

h_{2pt} = cost to carry a unit of finished product p in inventory at stage 2 from period t to t + 1

b_{1kt} = quantity of resource type k available at stage 1 in period t (k = 1,2, ..., K)

b_{2rt} = quantity of resource type r available at stage 2 in period t (r = 1,2, ..., R)

a_{ipg} = number of units of senifinished product i used to make one unit of finished product p by process g at stage 2.

e_{ijk} = number of units of stage 1 resource k required to produce one unit of semifinished product i by process j

f_{pgr} = number of units of stage 2 resource r required to produce one unit of finished product p by process g

P^1_{pt} = minimum amount of product p available for sale in period t

P^2_{pt} = maximum possible sales of product p in period t.

The objective is to maximize:

$$\sum_{t=1}^{T} \sum_{p=1}^{n_2} \left\{ R_{pt} S_{pt} - \sum_{i=1}^{n_1} \left[\sum_{j=1}^{J_i} C_{1ijt} X_{ijt} + h_{1it} I_{1it} \right] - \sum_{p=1}^{n_2} \left[\sum_{g=1}^{Q_p} C_{2pgt} Y_{pgt} + h_{2pt} I_{2pt} \right] \right\}$$

subject to

$$I_{1it} = I_{1i,t-1} + \sum_{j=1}^{J_i} X_{ijt} - \sum_{p=1}^{n_2} \sum_{q=1}^{Q_p} a_{ipg} Y_{pgt}$$

$$I_{2pt} = I_{2p,t-1} + \sum_{q=1}^{Q_p} Y_{pgt} - S_{pt}$$

$$\sum_{i=1}^{n_1} \sum_{j=1}^{J_i} e_{ijk}\, x_{ijt} \leq b_{1kt}$$

$$\sum_{p=1}^{n_2} \sum_{g=1}^{Q_p} f_{pgr} Y_{pgt} \leq b_{2rt}$$

$$P^1_{pt} \leq S_{pt} \leq P^2_{pt}$$

$$I_{1it},\ I_{2pt},\ x_{ijt},\ Y_{pgt} \geq 0.$$

For all i, k, p, r and t.

In treating sales as a variable, there was effectively an addition of third stage which may be called "marketing stage." This draws on the finished goods inventory and delivers to the customer, all in the same period. Its activities generate no costs, only revenues.

A flow diagram (as given by Johnson) of this multistage structure may be shown as in Figure 2. Production planning models also exist for cases when demand is dependent on service time or the demand is stochastic. Other types of problems are process selection and blending. In the process selection problem, there are fixed production requirements for each of a number of products during a period. Each product may have several alternative ways (sources, routings, and processes) by which it can be produced. The unit costs and resources utilized will depend on the process selected. Each production resource has a given limited availability in the period, and the various products will compete for this capacity according to the particular production processes selected for each product. The problem is to determine how much of each product to make by each process to minimize production costs, subject to constraints imposed by resource limitations and the requirements that given

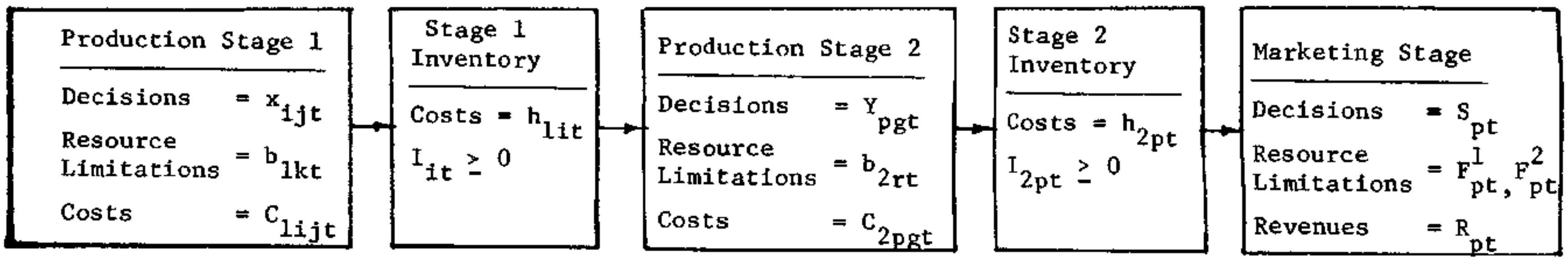

Figure 2. Flow Chart of a Multistage Structure.

total amounts of each product be produced. The blending problem occurs when a production process involves mixing several raw materials to make a product conforming to given specifications, and there are a number of alternative combinations (blends) of these materials that will produce an acceptable product. Since the materials have different properties, resulting in their making differing contributions toward meeting the specifications, and have different unit costs, the problem is to determine the least-cost blend of materials that will result in a satisfactory product. Models also exist, which consider the production rate change costs, backlogging and overtime decision. Models with convex and concave (functions) costs can be solved using convex cost or concave cost algorithms respectively.

In one of the IBM publications,[4] the applications of production planning in a textile environment have been dealt with in great detail. A textile mill may operate on make-to-order or make-to-inventory, production planning techniques can be used in either case.

It (the IBM publication) states that the key benefit of production planning is that it allows management to employ company resources in the most effective manner. At the same time, it is possible to improve other functions of the industry such as customer order servicing, marketing, and forecasting. Determining the expected value of additional resources and inprocess inventories is covered as a part of production planning. The production planning concept includes fast simulation of alternate production plans. This can be illustrated through a small example. Supposing there is a management meeting to consider changes to the current production schedules. The marketing department is confident that a new style of fabric which utilizes the same resources as are being consumed by products already on the production schedule can be sold for a relatively larger profit margin. The problem is to determine whether this new product can be fitted into the current production schedule without affecting the company's marketing policies regarding other products, and at the same time increase company's profits. The first step is to determine the loom capacity requirements to meet the sales forecast for the new product. This is checked with the loom capacity available during that period. If it is within the loom schedule horizon, then a new schedule is generated considering factors as

1. Beam runout.
2. Beam availability.
3. Cost of running short warps.
4. Cost of cutting out warps.

The next step is to determine whether the spinning department can support the revised loom schedule. The production planning system calculates:

1. Material requirements at various processing steps back to raw material.

2. Manufacturing capacities at the required cost centers.

If all the requirements can be met, then the tentative production schedule becomes the new production target. It is essential that all the data concerning costs, sales forecasts, material requirements, and availability be reasonable estimates of what will actually happen if detailed planning is to be effective. Production planning can also be used for cost planning and control. The anticipated production at standard costs may be used to predict cash flows.

CHAPTER III

DISCUSSION OF THE MODEL

Assumptions Made in the Model

The model proposed is valid for any composite textile mill, manufacturing any number of fabric (greige) styles; all of which follow the same production process and utilize the same resources.

No shortages of material are allowed at any of the stages. The quantity of any fabric to be sold in any period has been treated as a decision variable. At the same time, there is a constraint on sales limits based on forecasts.

As mentioned earlier, it has been assumed that there are no production bottlenecks up to the drawing stage; in other words, the capacity up to the drawing stage is sufficient to cover any production requirements possible at spinning or weaving stages. The only active constraint up to the drawing stage is the availability of raw material in any period.

General Discussion

Provision has been made to permit the use of overtime. The overhead costs are different for regular time and overtime. All the fabric styles being manufactured are processed on the same type of machines.

There is provision for selling yarn and also there is the possibility of manufacturing fabric using yarn bought from outside (in case of shortage). The price at which yarn may be sold is for obvious reasons lower than the price for which it can be bought.

There is a minimum production requirement for every fabric style in accordance with the management marketing strategy. This (minimum production requirement) may be necessary to keep the company in business. A particular fabric style may yield relatively very low profit, but it may be advisable to produce that style since its sales volume is high and certain. There is no fixed charge in the model on the labor or machine time. Fixed charges are mathematical constants and do not affect the optimal solution in any way.

The unit variable revenue from sale of any of the products is net of any distribution costs and losses for goods sold on seconds. This loss must be calculated from forecasts of quantity of product expected to be inferior in quality. The inventory carrying costs at any stage are based on the capital involved (in products in inventory), risk of obsolescence, and the length of time for which products are held in inventory.

The unit variable production costs in weaving include overhead as well as the raw material. The unit variable production costs in spinning and roving include only the overhead and not the material costs.

The model is simple to understand, and can be applied easily, but yet is a realistic description of a composite spinning-weaving production facility.

Model Development

List of Symbols to be Used in the Objective Functions

Decision variables:

$S_{p,t}$ = planned sales (in 1000 yds.) of product p in period t

$X_{p,t,v}$ = number of units (in 1000 yds.) of product p to be manufactured in period t using combination v

$X^1_{p,t,v}$ = number of units (in 1000 yds.) of product p manufactured in period t, using yarn bought from outside (utilizing combination v)

$S_{i,p,t}$ = number of units (lbs.) of yarn type i, product p, sold in period t

$I_{p,t}$ = net inventory of fabric p (in units of 1000 yds.) in period ending t

$Y_{i,p,t,v}$ = weight of yarn (lbs.) type i for product p manufactured in period t using combination v

$Z_{i,p,t,v}$ = weight (in lbs.) of roving type i for product p manufactured in period t using combination v

$I_{i,k,p,t}$ = net on hand inventory (in lbs.) of material type i for product p at stage k in period t.

Cost variables:

$\phi_{p,t}$ = unit variable revenue in dollars (net of any selling and distribution costs) from the sale of a unit (1000 yds.) of cloth p in period t

$\phi_{i,p,t}$ = unit variable revenue in dollars from selling a unit (lb.) of yarn type i of product p in period t

$h_{p,t}$ = average inventory carrying costs in dollars per period for a unit of product p in period t

$C_{p,t,v}$ = variable production costs in dollars for a unit of product p in period t using combination v in weaving

$C^1_{p,t,v}$ = variable production cost in dollars for a unit of p in period t using combination v for yarn bought from outside

$C_{i,p,t,v}$ = unit variable production costs in dollars for manufacturing a pound of yarn type i for product p in period t using combination v

$C^1_{i,p,t,v}$ = production costs in dollars associated with the production of a pound of roving

$h_{i,k,p,t}$ = inventory carrying costs in dollars per pound of material type i for product p at stage k in period t.

K = 1 : Roving stage

= 2 : Yarn stage

P = 1,2, ..., n (types of cloth)

t = 1,2, ..., m

v = 1 : Regular time

= 2 : Overtime

Objective function:

$$\text{Max} \sum_{t=1}^{m} \left\{ \sum_{p=1}^{n} \left[\phi_{p,t} S_{p,t} + \sum_{i=1}^{2} \phi_{i,p,t} S_{i,p,t} \right] - \sum_{p=1}^{n} \left[\sum_{v=1}^{2} \left(C_{p,t,v} X_{p,t,v} \right.\right.\right.$$

$$\left.\left. + C^1_{p,t,v,} X^1_{p,t,v} \right) + h_{p,t} I_{p,t} \right] - \sum_{i=1}^{2} \sum_{p=1}^{n} \left[\sum_{v=1}^{2} \left(C_{i,p,t,v} Y_{i,p,t,v} \right.\right.$$

$$\left.\left.\left. + C^1_{i,p,t,v,} Z_{i,p,t,v} \right) + \sum_{k=1}^{2} h_{i,k,p,t} I_{i,k,p,t} \right] \right\}$$

The first two terms represent the revenues resulting from the sale of fabric and yarn respectively. The next two terms represent the production costs incurred at the weaving stage, for fabric made from homemade yarn and purchased yarn respectively. The production costs include the overhead costs in weaving, as well as the material costs. The fifth term represents the inventory carrying costs for the greige fabric. The next two terms take into account the production costs incurred in spinning and roving stages respectively. The production costs include the overheads but not the material costs. The last term is the inventory carrying costs for yarn and roving. Inventory carrying costs at any stage are based on the capital locked up in inventory at that particular stage, risk of obsolescence and the length of time for which the goods are held in inventory.

Constraints

Weaving

Machine Time Utilization (weaving):

M_t = Regular machine time (loom hours) available in period t.

M_t^1 = Extra time (loom hours) available in period t.

O_p = Loom hours required to produce a unit (1000 yds.) of product p.

The first constraint is that the total weaving time utilized be less than equal to the total weaving time available.

$$\sum_p \left\{ O_p \left[\sum_v \left(X_{p,t,v} + X^1_{p,t,v} \right) \right] \right\} \quad .\mathrm{LE.} \quad M_t + M_t^1 \tag{1}$$

The second constraint required is that the weaving time consumed in manufacturing fabric woven on regular time be less than equal to the regular time available in the same period.

$$\sum_p \left\{ O_p \left[X_{p,t,1} + X^1_{p,t,1} \right] \right\} \quad .\mathrm{LE.} \quad M_t \tag{2}$$

Labor Time Utilization (weaving):

L_t = Regular manhours available in period t.

L_t^1 = Overtime manhours available in period t

B_p = Manhours required to produce a unit of product p.

The two constraints on labor time utilization are based on the same arguments as those for machine time utilization.

$$\sum_p \left\{ B_p \left[\sum_v \left(X_{p,t,v} + X^1_{p,t,v} \right) \right] \right\} \quad .LE. \quad L_t + L_t^1 \tag{3}$$

$$\sum_p \left\{ B_p \left[X_{p,t,1} + X^1_{p,t,1} \right] \right\} \quad .LE. \quad L_t \tag{4}$$

Yarn Consumption Limit:

This constraint is requied to ensure that the yarn (any type) consumed during a period be less than equal to yarn (same type) available in the same period.

Let $W_{p,i}$ = Weight in pounds of yarn type i required for a unit (1000 yds.) of fabric p.

T = Lead time in manufacture of cloth.

$$W_{p,i} \sum_v X_{p,t,v} \quad .LE. \quad \sum_v Y_{i,p,t-T,v} + I_{i,2,p,t-1} - S_{i,p,t} \tag{5}$$

Inventory Balance For Yarn:

This constraint ensures that the inventory of fabric at the end of any period be always at a positive level or zero; since no shortages are allowed.

$$I_{p,t} \quad .EQ. \quad I_{p,t-1} + \sum_v \left(X_{p,t-T,v} + X^1_{p,t-T,v} \right) - S_{p,t} \tag{6}$$

Sales Limits on Fabrics:

This constraint ensures that a minimum desired level of each of the products be produced, and also the planned sales level should not go beyond the maximum sales forecast.

$F^1_{p,t}$ = Minimum sales desired for product p in period t.

$F_{p,t}$ = Maximum sales possible for product p in period t.

$$F^1_{p,t} \text{ .LE. } S_{p,t} \text{ .LE. } F_{p,t} \tag{7}$$

Spinning Time Utilization

Machine Time Utilization (Spinning):

MY_t = Regular spindle hours available in period t.

MY^1_t = Extra spindle hours available in period t.

$OY_{i,p}$ = Spindle hours required to produce a pound of yarn type i for fabric p.

As in the case of weaving, two constraints are required for the machine time utilization in spinning. The first constraint ensures that the time consumed in manufacturing all the yarn be less than equal to total spindle hours available in the same period; and the second constraint ensures that the regular spinning time consumed be less than equal to regular spinning time available.

$$\sum_i \sum_p OY_{i,p} \sum_v Y_{i,p,t,v} \quad \text{.LE.} \quad MY_t + MY^1_t \tag{8}$$

$$\sum_i \sum_p \left[OY_{i,p} \, (Y_{i,p,t,1})\right] \quad \text{.LE.} \quad MY_t \tag{9}$$

Manhours Utilization (Spinning):

LY_t = Regular manhours available in period t.

LY_t^1 = Overtime manhours available in period t.

$BY_{i,p}$ = Manhours required to produce a pound of yarn type i for product p.

Based on the same arguments as for machine time utilization, two constraints are required for manhours utilization also.

$$\sum_i \sum_p \left[BY_{i,p} \sum_v Y_{i,p,t,v}\right] \quad .LE. \quad LY_t + LY_t^1 \tag{10}$$

$$\sum_i \sum_p \left[BY_{i,p} \cdot Y_{i,p,t,1}\right] \quad .LE. \quad LY_t \tag{11}$$

Limit on Market for Yarn Sold:

This constraint ensures that the planned sales for any type of yarn be less than equal to sales level forecast for that particular yarn.

$$S_{i,p,t} \quad .LE. \quad F_{i,p,t} \tag{12}$$

where, $F_{i,p,t}$ is the maximum possible sales (forecase) for yarn type i of fabric p in period t.

Inventory Balance for Yarn:

This constraint ensures that there are no shortages of any type of yarn.

$$I_{i,2,p,t} \ .EQ. \ I_{i,2,p,t-1} + \sum_v Y_{i,p,t-T,v} - S_{i,p,t} - W_{p,i} \sum_v X_{p,t,v} \tag{13}$$

where T is the lead time for the manufacture of yarn.

Roving Time Utilization

Machine Time Utilization (Roving):

As in weaving and spinning two constraints are required on the utilization of roving time.

MR_t = Regular machine hours available in roving in period t.

MR_t^1 = Extra machine hours available in roving in period t.

$OR_{i,p}$ = Machine hours required to produce a pound of roving type i for fabric p.

$$\sum_i \sum_p \left(OR_{i,p} \sum_v Z_{i,p,t,v} \right) \quad .LE. \quad MR_t + MR_t^1 \tag{14}$$

$$\sum_i \sum_p \left(OR_{i,p} \cdot Z_{i,p,t,1} \right) \quad .LE. \quad MR_t \tag{15}$$

Manhours Limit (Roving):

As for machine time consumption limit in roving, two constraints are required on the consumption limits of manhours in roving also.

LR_t = Regular manhours available in period t.

LR_t^1 = Overtime manhours available in period t.

$BR_{i,p}$ = Manhours required to product a pound of roving type i for fabric p.

$$\sum_i \sum_p \left(BR_{i,p} \sum_v Z_{i,p,t,v} \right) \quad .LE. \quad LR_t + LR_t^1 \tag{16}$$

$$\sum_i \sum_p \left(BR_{i,p} \cdot Z_{i,p,t,1} \right) \quad .LE. \quad LR_t \tag{17}$$

Roving Consumption Limit:

This constraint ensures that the roving consumed in any period be less than equal to the roving available in the same period.

$WR_{p,i}$ = Weight in pounds of roving type i for fabric p required to manufacture a pound of yarn type i for fabric p.

$$WR_{p,i} \sum_v Y_{i,p,t,v} \quad .LE. \quad \sum_v Z_{i,p,t,v} + I_{i,1,p,t-1} \tag{18}$$

Raw Material Consumption Limit:

This constraint ensures that the quantity of roving manufactured in any period be less than equal to the raw material (draw frame sliver) available in the same period.

$a_{i,p}$ = Raw material in pounds required to make one pound of roving type i for fabric p.

I_t = Weight in pounds of raw material available in period t.

$$\sum_i \sum_p \left(a_{i,p} \sum_v Z_{i,p,t,v}\right) \quad .LE. \quad I_t \tag{19}$$

Inventory Balance for Roving:

This constraint ensures that no shortages of roving may occur.

$$I_{i,1,p,t} \quad .EQ. \quad I_{i,1,p,t-1} + \sum_v Z_{i,p,t-T,v} - WR_{p,i} \sum_v Y_{i,p,t,v} \tag{20}$$

Non-negativity Constraints:

These constraints ensure that there are no meaningless solutions such as negative production, sales, or inventory.

$$S_{p,t},\ S_{i,p,t},\ X_{p,t,v},\ X^1_{p,t,v},\ I_{p,t},\ Y_{i,p,t,v},\ Z_{i,p,t,v},\ I_{i,k,p,t} \tag{21}$$

be all greater than equal to zero. For all i,p,t.

CHAPTER IV

DISCUSSION OF RESULTS

The model discussed earlier was tested by supplying data for a hypothetical textile mill. The capacity of the mill in terms of manpower and machines available was representative of a medium size mill. In order to reduce the size of the problem and remain within the limited computer storage space available, three fabric styles were considered. The production capacities and fabric styles specifications are given in Appendices I and II. The details regarding production costs and material costs were taken from T. A. Campbell Jr.'s[1] book on textile costing.

The planning horizon of one year was broken into two periods of six months each. Both regular and overtime production was scheduled. The effect on the optimal solution was studied by solving for various initial inventories, sales limits, production costs, selling prices for yarns and fabrics and with or without the possibility of buying yarns.

Table 1 represents the case when there are no independent constraints on the utilization of regular time, i.e., the constraints that total fabric and yarn manufactured during regular time in a period be less than equal to total regular weaving and spinning time available respectively. Without these constraints, the fabric manufactured on regular time exceeded the regular weaving time available, as can be seen from the results in Table 1. Another point observed was that although the profit margin (net of any variable costs involved) on all the three styles of fabrics was the same (7%), the planned sales

Table 1. No Constraint on Regular Time Utilization

Decision Variables			
No.	Variable	Solution Value	Dual Value
1	$X_{1,1,1}$	11,845.00	0.197
2	$S_{1,2}$	9995.40	0.191
3	$S_{1,1}$	18,500.00	0.0
4	$S_{2,1,1}$	10,000.00	0.0
5	$X_{2,1,1}$	3664.70	0.0
6	$X_{3,1,1}$	3813.40	0.0
7	$S_{1,3,2}$	10,000.00	0.0
8	$S_{1,1,2}$	10,000.00	0.0
9	$S_{2,1,2}$	10,000.00	0.0
10	$X_{2,2,1}$	4225.70	0.0
11	$I_{1,2,2,1}$	583,500.00	0.0
12	$S_{2,3,2}$	10,000.00	0.0
13	$I_{1,2,3,1}$	10,000.00	0.0
14	$I_{1,1}$	3345.40	0.0
15	$S_{2,1}$	9064.70	0.0
16	$X'_{2,2,1}$	2274.30	2.0
17	$S_{3,1}$	7813.40	0.0
18	$X'_{3,2,1}$	5800.00	1.5
19	$X'_{1,2,1}$	6650.00	0.103
20	$Y_{2,3,1,1}$	7611.90	0.0
21	$S_{1,2,1}$	10,000.00	0.0

Table 1. No Constraint on Regular Time Utilization (Continued)

Decision Variables			
No.	Variable	Solution Value	Dual Value
22	$I_{2,2,3,1}$	10,000.00	0.0
23	$I_{2,2,1,1}$	3174.20	0.0
24	$I_{2,2,2,1}$	420,930.00	0.0
25	$S_{2,3,1}$	10,000.00	0.0
26	$I_{1,2,1,2}$	0.0	0.0
27	$I_{1,2,2,2}$	0.0	0.0
28	$I_{1,2,3,2}$	0.0	0.0
29	$I_{2,2,1,2}$	0.0	0.0
30	$I_{2,2,2,2}$	0.0	0.0
31	$I_{2,2,3,2}$	0.0	0.0
32	$S_{2,2,2}$	10,000.00	0.0
33	$S_{1,1,1}$	10,000.00	0.0
34	$S_{2,2,1}$	10,000.00	0.0
35	$S_{1,2,2}$	5000.00	0.0
36	$Y_{2,1,2,1}$	6825.00	0.0
37	$I_{1,2,1,1}$	10,000.00	0.0
38	$Y_{2,2,2,1}$	9108.80	0.0
39	$S_{1,3,1}$	10,000.00	0.0

Table 1. No Constraint on Regular Time Utilization (Concluded)

Optimal Solution: Profit = $5,273,670.07.

Decision variables at nonbasic (lower limit) value are: $S_{2,2} = 6500.00$

$S_{3,2} = 5800.00$

Unutilized manhours in spinning, period 1 = 57481000.00

Unutilized manhours in spinning, period 2 = 57393000.00

All other decision variables are at their nonbasic value, i.e., 0.0.

Changes made to the original data: $F_{1,2,2} = 5000.00$

were different. This result is attributable not only to the affect of sales limits, but also to the difference in amount of resources consumed by the different fabric styles. The sales volume for fabric style one in period one was found to be at its upper sales limit, whereas for styles two and three, sales volume was in between the lower and upper sales limits. In period two, both styles two and three were found to be at their lower limits, whereas style one was at a level between the lower and upper limits. Although inventory carrying costs are lowest for style three and highest for style two, inventory was planned for only style one in period one. No inventories were planned in period two since the model is a two-period model and inventories are never planned for the last period. To apply in practice, the model must be reviewed every period (or earlier if the situation demands). It can be observed that the sale of certain types of yarns has been allowed to their maximum limits, whereas no sales are allowed for some other types of yarns. Weaving time has been utilized to the maximum, whereas there is some unutilized spinning capacity. This result shows that the mill structure is not balanced and the overall production may be increased by having more looms. The dual value for the sale of fabric style one in period two and also the amount of fabric one being manufactured was positive. This result indicates that a marginal increase in profit is possible by increasing the production for fabric style one. Further production was not possible as no more weaving capacity was available.

Table 2 represents the case when the initial (starting) inventories for yarns and fabrics were reduced. The independent constraints on the consumption of regular time,(i.e. the amount of fabric and yarn

Table 2. With Constraints on Regular Time Utilization

Decision Variables			
No.	Variable	Solution Value	Dual Value
1	$X'_{3,1,1}$	7227.60	0.0
2	$S_{1,2}$	14,286.00	0.108
3	$X'_{3,2,1}$	1164.20	0.0
4	$X_{2,2,2}$	4881.30	0.0
5	$X_{2,1,2}$	3009.10	0.0
6	$S_{1,1,2}$	10,000.00	0.0
7	$S_{2,1,2}$	10,000.00	0.0
8	$S_{1,1}$	18,500.00	0.0
9	$I_{1,2,2,1}$	673,250.00	0.0
10	$I_{1,2,3,1}$	228,800.00	0.0
11	$X_{1,1,1}$	1293.30	0.0
12	$X'_{1,2,1}$	11,213.00	1.7
13	$X'_{1,1,1}$	4808.20	1.95
14	$I_{2,2,2,1}$	495,200.00	2.01
15	$X_{3,1,1}$	1772.40	1.46
16	$X'_{3,2,2}$	2594.80	1.5
17	$X_{1,1,2}$	7398.50	0.0
18	$X'_{2,1,2}$	1879.70	0.0
19	$S_{1,2,1}$	10,000.00	0.0
20	$I_{2,2,3,1}$	504,710.00	0.0
21	$X_{3,2,1}$	2041.00	0.0
22	$S_{2,1}$	8388.90	0.0

Table 2. With Constraints on Regular Time Utilization (Continued)

Decision Variables			
No.	Variable	Solution Value	Dual Value
23	$S_{2,3,1}$	10,000.00	0.0
24	$I_{1,2,1,2}$	0.0	0.0
25	$I_{1,2,2,2}$	0.0	0.0
26	$X'_{2,2,2}$	1618.70	0.0
27	$I_{1,2,3,2}$	0.0	0.0
28	$I_{2,2,2,2}$	0.0	0.0
29	$I_{2,2,3,2}$	359,190.00	0.0
30	$S_{2,2,1}$	10,000.00	0.0
31	$S_{1,1,1}$	10,000.00	0.0
32	$S_{2,1,1}$	10,000.00	0.0
33	$S_{2,2,2}$	10,000.00	0.0
34	$Y_{2,2,1,1}$	9108.80	0.0
35	$S_{1,3,1}$	10,000.00	0.0
36	$Y_{2,3,1,1}$	366,800.00	0.0
37	$I_{1,2,1,1}$	360,060.00	0.0
38	$I_{2,2,1,1}$	271,860.00	0.0
39	$S_{1,2,2}$	5000.00	0.0
40	$S_{1,3,2}$	10,000.00	0.0
41	$X_{1,2,2}$	3073.40	0.0
42	$S_{2,3,2}$	10,000.00	0.0
43	$S_{3,1}$	11,500.00	0.0

Table 2. With Constraints on Regular Time Utilization (Concluded)

Optimal Solution: Profit = \$3,912,754.30

Decision variables at nonbasic (lower limit) value are: $S_{2,2} = 6500.00$
$S_{3,2} = 5800.00$

Unutilized manhours in spinning, period 1 = 74157000.00

Unutilized manhours in spinning, period 2 = 35000000.00

All other decision variables are at their nonbasic value, i.e., 0.0

Changes made to the original data:

$F_{1,2,2}$	=	5000.00
$I_{1,2,1,0}$	=	1,000,000.00
$I_{2,2,1,0}$	=	990,000.00
$I_{1,2,2,0}$	=	900,000.00
$I_{2,2,2,0}$	=	300,000.00
$I_{1,2,3,0}$	=	200,000.00
$I_{2,2,3,0}$	=	150,000.00
$I_{1,0}$	=	5000.00
$I_{2,0}$	=	3500.00
$I_{3,0}$	=	2500.00

manufactured on regular time should be less than equal to regular time available in weaving and spinning respectively) were introduced. It can be seen that the overall profit decreased considerably. With the introduction of new constraints, regular time production costs for some of the material manufactured in case one was now changed to overtime costs.

As we saw in case one, total amount of fabric manufactured on regular time exceeded the regular time available. The overtime costs being higher than regular tim e costs when the new constraints (on regular time consumption) were introduced; the total production costs went up, moreover with lower initial inventories than that in case one; more material had to be manufactured to come up to the same sales levels, as a result the overall production costs for case two were much higher than for case one and consequently the net profit decreased.

Table 3 represents the case when sales limits on the fabrics were lowered by seven percent, but the profit margins were raised by five percent. The sales limits were lowered to show the effect of increase in profit, more prominently. As can be seen from the results in Table 3, even with lower level of sales, overall profit was higher than those in cases one and two. The effect of lowering the upper sales limit could not play much of a role in decreasing the profit since most of the fabrics in the earlier cases (one and two) were being manufactured at a level lower than their upper sales limits, and a small drop in the sales limit did not have much effect on the net profit. But, the increase in profit per unit of goods sold had a very significant effect which is shown by the increase in overall profit.

In Table 4 are the results for the case when yarn cannot be

Table 3. Effect of Increasing Profit Margins on Fabrics by 5%

Decision Variables			
No.	Variable	Solution Value	Dual Value
1	$X_{2,1,2}$	3664.70	0.155
2	$X_{2,2,2}$	4189.20	0.148
3	$S_{1,1,1}$	10,000.00	0.0
4	$X_{1,1,2}$	1168.90	0.0
5	$S_{3,1}$	7813.40	0.0
6	$S_{1,3,2}$	10,000.00	0.0
7	$S_{1,1,2}$	10,000.00	0.0
8	$S_{2,1,2}$	10,000.00	0.0
9	$X'_{3,2,1}$	5394.00	0.0
10	$I_{1,2,2,1}$	583,500.00	0.0
11	$S_{2,3,2}$	10,000.00	0.0
12	$I_{1,2,3,1}$	10,000.00	0.0
13	$S_{1,1}$	16,650.00	0.0
14	$I_{1,1}$	5195.40	1.78
15	$S_{2,1}$	9064.70	-2.04
16	$X'_{2,2,1}$	1410.00	2.12
17	$X'_{2,2,2}$	445.76	-1.57
18	$X_{3,1,1}$	3813.40	1.58
19	$X'_{1,2,1}$	7559.00	0.103
20	$Y_{2,3,1,1}$	7611.90	0.0
21	$S_{1,2,1}$	10,000.00	0.0
22	$I_{2,2,3,1}$	10,000.00	0.0

Table 3. Effect of Increasing Profit Margins on Fabrics by 5% (Continued)

Decision Variable			
No.	Variable	Solution Value	Dual Value
23	$I_{2,2,1,1}$	3174.10	0.0
24	$I_{2,2,2,1}$	420,930.00	0.0
25	$S_{2,3,1}$	10,000.00	0.0
26	$I_{1,2,1,2}$	0.0	0.0
27	$I_{1,2,2,2}$	0.0	0.0
28	$I_{1,2,3,2}$	0.0	0.0
29	$I_{2,2,1,2}$	0.0	0.0
30	$I_{2,2,2,2}$	0.0	0.0
31	$I_{2,2,3,2}$	0.0	0.0
32	$S_{2,2,2}$	10,000.00	0.0
33	$S_{2,1,1}$	10,000.00	0.0
34	$S_{2,2,1}$	10,000.00	0.0
35	$S_{1,2,2}$	10,000.00	0.0
36	$S_{1,3,1}$	10,000.00	0.0
37	$I_{1,2,1,1}$	10,000.00	0.0
38	$Y_{2,1,2,1}$	6825.90	0.0
39	$Y_{2,2,2,1}$	5478.50	0.0
40	$X_{1,1,1}$	10676.00	0.0
41	$S_{1,2}$	12754.00	0.0

Table 3. Effect of Increasing Profit Margins on Fabrics by 5% (Concluded)

Optimal Solution: Profit = $5,581,282.57

Decision variables at nonbasic (lower limit) value are: $S_{1,2} = 8370.00$
$S_{2,2} = 6045.00$
$S_{3,2} = 5394.00$

Unutilized manhours in spinning, period 1 = 57481000.00
Unutilized manhours in spinning, period 2 = 57438000.00
All other decision variables are at their nonbasic value, i.e., 0.0

Changes made to the original data:

$F_{1,2,2} = 10,000.00$

$F'_{1,1} = 7440.00$

$F'_{2,1} = 4185.00$

$F'_{3,1} = 2520.00$

$F'_{1,2} = 8370.00$

$F'_{2,2} = 6045.00$

$F'_{3,2} = 5394.00$

$F_{1,1} = 16,650.00$

$F_{2,1} = 9900.00$

$F_{3,1} = 10,350.00$

$F_{1,2} = 15,750.00$

$F_{2,2} = 12,600.00$

$F_{3,2} = 12,150.00$

$\phi_{i,t} = \$178.5$

$\phi_{2,t} = \$204.75$

$\phi_{3,t} = \$157.50$

Table 4. Yarn Purchase Not Allowed

Decision Variables			
No.	Variable	Solution Value	Dual Value
1	$X_{2,1,2}$	3571.80	0.12
2	$X_{2,2,2}$	4282.10	0.134
3	$S_{1,1,1}$	10,000.00	0.0
4	$X_{1,1,2}$	1284.60	0.0
5	$S_{1,1}$	21,879.00	0.0
6	$X_{3,1,1}$	3906.70	0.0
7	$S_{2,3,1}$	10,000.00	0.0
8	$S_{1,1,2}$	10,000.00	0.0
9	$X_{1,2,1}$	13,429.00	0.0
10	$I_{2,1}$	2217.90	0.0
11	$I_{1,2,2,1}$	596,220.00	0.0
12	$X_{3,2,1}$	693.28	0.0
13	$I_{1,2,3,1}$	0.0	0.0
14	$X_{1,2,2}$	353.64	-1.78
15	$S_{2,1}$	6753.90	-2.04
16	$S_{1,2}$	13,782.00	2.17
17	$I_{3,1}$	5106.70	-1.8
18	$Y_{2,3,2,1}$	56,034.00	1.91
19	$Y_{2,3,1,1}$	3806.00	0.0
20	$S_{1,2,1}$	10,000.00	0.0
21	$I_{2,2,3,1}$	0.0	0.0
22	$I_{2,2,1,1}$	327.18	0.0

Table 4. Yarn Purchase Not Allowed (Continued)

Decision Variables			
No.	Variable	Solution Value	Dual Value
23	$I_{2,2,2,1}$	430,160.00	0.0
24	$Y_{1,3,2,1}$	84,320.00	0.0
25	$I_{1,2,1,2}$	0.0	0.0
26	$I_{1,2,2,2}$	0.0	0.0
27	$I_{1,2,3,2}$	0.0	0.0
28	$I_{2,2,1,2}$	0.0	0.0
29	$I_{2,2,2,2}$	0.0	0.0
30	$I_{2,2,3,2}$	0.0	0.0
31	$S_{2,2,2}$	10,000.00	0.0
32	$S_{2,1,1}$	10,000.00	0.0
33	$S_{2,2,1}$	10,000.00	0.0
34	$S_{1,2,2}$	10,000.00	0.0
35	$S_{1,3,1}$	10,000.00	0.0
36	$I_{1,2,1,1}$	1,579,800.00	0.0
37	$S_{2,1,2}$	10,000.00	0.0
38	$Y_{2,2,2,1}$	5478.50	0.0
39	$S_{1,3,2}$	10,000.00	0.0
40	$S_{2,3,2}$	10,000.00	0.0
41	$X_{1,1,1}$	10,594.00	0.0
42	$Y_{2,1,2,1}$	1,183,900.00	0.0

Table 4. Yarn Purchase Not Allowed (Concluded)

Optimal Solution: Profit = \$5,508,000.00

Decision variables at the nonbasic value are: $S_{3,1} = 2800.00$

$S_{2,2} = 6500.00$

$S_{3,2} = 5800.00$

Unutilized manhours in spinning, period 1 = 57541000.00

Unutilized manhours in spinning, period 2 = 39631000.00

All other decision variables are at their nonbasic value, i.e. 0.0

Changes made to the original data: No possibility of purchasing Yarn be bought to manufacture any of the fabrics. The results show a drop in profit as compared to case three. This result is obvious since in the previous case fabric one was being manufactured on yarn bought from outside. With the introduction of the new restriction, less of the fabric was was now available for sale. This effect can also be seen by the increase in dual value of the sales variable for fabric style two from zero in the previous case to 2.17 in the present case.

Table 5 contains the results for the case when there are no initial inventories of yarns and fabrics. The profit margins are the same as in the earlier case. The results show a drop in the net profit as expected. With no initial inventory, less amounts of the fabrics were available for sale; as can be seen from the values of the sales variables, most of them are at their nonbasic value--lower limit as a result the overall profit decreased.

In Table 6 results are shown when the profit margins on yarn sales have been reduced by ten cents a unit, i.e., a drop of fourteen percent. All other conditions were kept the same. The results show no change in the value (contribution) of all the variables, but the reduced profit margin on yarn sales resulted in a drop in the overall profit.

Table 7 represents the case when production costs for the fabrics were raised by a dollar per unit. As can be seen from the results, there is no change in the value (contribution) of all the variables; but the overall profit has gone down because of the higher production costs.

From the above results, we can thus easily see the effect on company's profits by marginal changes in the resources, profit margins, and production costs.

Table 5. No Initial Inventories of Yarns and Fabrics

Decision Variables			
No.	Variable	Solution Value	Dual Value
1	$Y_{2,2,1,1}$	756,600.00	0.0
2	$Y_{2,2,2,1}$	356,800.00	0.134
3	$X_{1,1,1}$	8000.00	0.0
4	$Y_{1,1,1,1}$	921,200.00	0.0
5	$X_{2,1,2}$	4589.60	0.0
6	$Y_{1,2,1,1}$	1,038,300.00	0.0
7	$X_{3,1,1}$	2800.00	0.0
8	$Y_{1,3,1,1}$	310160.00	0.0
9	$X_{1,2,1}$	8924.10	0.0
10	$I_{1,2,1,1}$	1,188,300.00	0.0
11	$X_{2,2,2}$	3488.90	0.0
12	$I_{1,2,2,1}$	0.0	0.0
13	$X_{3,2,1}$	5800.00	0.0
14	$X_{1,2,2}$	1421.30	0.0
15	$I_{2,1}$	3011.10	2.02
16	$Y_{2,1,2,1}$	891,430.00	1.78
17	$Y_{2,3,1,2}$	195,920.00	1.86
18	$X_{2,1,1}$	2921.50	2.53
19	$Y_{2,3,2,1}$	395120.00	2.4
20	$Y_{2,3,1,1}$	0.0	0.0
21	$I_{2,2,2,1}$	0.0	0.0
22	$I_{2,2,3,1}$	0.0	0.0

Table 5. No Initial Inventories of Yarns and Fabrics (Continued)

Decision Variables			
No.	Variable	Solution Value	Dual Value
23	$I_{2,2,1,1}$	0.0	0.0
24	$Y_{1,2,2,1}$	487,630.00	0.0
25	$Y_{1,3,2,1}$	631,760.00	0.0
26	$I_{1,2,1,2}$	0.0	0.0
27	$I_{1,2,2,2}$	0.0	0.0
28	$I_{1,2,3,2}$	0.0	0.0
29	$I_{2,2,1,2}$	0.0	0.0
30	$I_{2,2,2,2}$	0.0	0.0
31	$I_{2,2,3,2}$	0.0	0.0
32	$S_{1,2,2}$	10,000.00	0.0
33	$S_{1,1,1}$	10,000.00	0.0
34	$S_{2,1,1}$	10,000.00	0.0
35	$S_{1,2,1}$	10,000.00	0.0
36	$S_{2,2,1}$	10,000.00	0.0
37	$S_{1,3,1}$	10,000.00	0.0
38	$S_{2,3,1}$	10,000.00	0.0
39	$S_{1,1,2}$	10,000.00	0.0
40	$S_{2,1,2}$	10,000.00	0.0
41	$S_{2,2,2}$	10,000.00	0.0
42	$S_{1,3,2}$	10,000.00	0.0
43	$S_{2,3,2}$	10,000.00	0.0
44	$Y_{2,1,1,1}$	691,600.00	0.0
45	$S_{1,2}$	10,345.00	0.0

Table 5. No Initial Inventories of Yarns and Fabrics (Concluded)

Optimal Solution: Profit = \$542,400.00

Decision variables at nonbasic (lower limit) value are:

$S_{1,1} = 8000.00$

$S_{2,1} = 4500.00$

$S_{3,1} = 2800.00$

$S_{2,2} = 6500.00$

$S_{3,2} = 5800.00$

All other decision variables are at the value 0.0.

Unutilized manhours in spinning, period 1 = 13932000.00

Unutilized manhours in spinning, period 2 = 2406500.00

Changes made to the original data: Initial Inventories of yarns and fabrics = 0.0
Profits are as in case three

Table 6. Effect of Reducing Profit on Yarn Sales by 14%

No change in the value of variables from that in Table 5.

Optimal Solution: Profit = $530,300.00

Changes made to the original data: $\phi_{i,p,t}$ = $0.6 for all i,p,t

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Table 7. Effect of Increasing Production Costs for Fabrics

No change in the value of variables from that in Table 5.

Optimal solution: Profit = $492,500.00

Changes made to the original data:

$C_{1,t,1}$ = $115.25

$C_{1,t,2}$ = $133.00

$C_{2,t,1}$ = $136.17

$C_{2,t,2}$ = $154.60

$C_{3,t,1}$ = $102.40

$C_{3,t,2}$ = $117.57

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The conclusions given below are based on the results obtained from solving the model discussed earlier.

Production planning can be used to plan company's production and inventory policies well ahead of time. This tool could undoubtedly increase the effectiveness of a manager's decisions. It gives management the ability to choose the best production plan out of the many alternatives available. Production planning also helps to identify areas of insufficient capacity. In the case solved, weaving operation was not balanced with the rest of the production line.

Production planning helped in setting up the pricing policy of the company. The results indicated that it was advantageous to have slightly higher selling prices and a loss in sales, as the net profit of the company was raised.

The effect of sudden changes in external elements involved became apparent through application of the model. The change in profit when yarn supply is limited or when production costs increases can be determined easily.

Recommendations

Production planning techniques have much wider applications than have been discussed in this thesis. The production models can be solved with different textile mill structures.

One possible improvement to the model will be the inclusion of fixed setup costs and charges for unutilized capacities. These can be done by formulating mixed linear-integer programming models. The model could also be extended to include both dyeing and finishing stages.

Much wider application of the model would be that for a very large size mill which has spinning and weaving plants at different locations. The problem then becomes that of determining yarn and fabrics quantities to be produced at the various centers and the specification of a distribution plan from the spinning to the weaving centers. This problem is a combined transportation-production planning problem.

Another problem that can be incorporated is that of process selection. Supposing facilities are available to produce both carded and combed cloth. Including the combing process increases the production costs but the profit for combed cloth is higher than carded (only) cloth. The problem is to determined how much (if any) combed cloth is to be produced.

In the model discussed, sales have been treated as a decision variable; this case may be compared with the policy of production to a given static demand. Another problem occurs when demand is undeterministic so that expected profit is calculated.

It is important to note that much work is required in forecasting. Production planning models can work well only if the sales forecasts are accurate. Poor forecasts may result in poor production planning, and the purpose of using mathematical techniques for production planning will be defeated.

APPENDIX I

SPECIFICATIONS FOR THE FABRIC STYLES MANUFACTURED

1. 90" width, 68 x 72; 30's W - 42's F
2. 39" width, 80 x 80; 30's W - 40's F
3. 40" width, 64 x 60; 30's W - 46's F

Number of Draper - 44" - x 2 looms = 1000.

Production (cloth) per 120 loom hours

1. 70,842 lbs. - 336,555 yds.
2. 36,465 lbs. - 145,860 yds.
3. 27,575 lbs. - 149,625 yds.

Average loom speed = 187 P.P.M.

Weave room efficiency = 96%

Number of spinning frames (Whitin) = 150

Production rates:

Warp yarn = 30's

T. M. = 4.25

T. P. I. = 23.3

Spindle r.p.m. = 10,200

Pounds per spindle (40 hrs.) = 1.084

Filling yarn:

Yarn Count	40's	42's	46's
Spindle r.pm.	11,075	10,900	10,825
T. M.	3.9	3.9	3.9

T.P.I.	24.7	25.3	26.4
% efficiency	95	95	95
Pounds/spindle (40 hrs.)	0.830	0.757	0.663
Spindles per frame	336	336	336

All data used have been calculated on the basis that the mill is operating five days per week and three shifts per day. Two days per week (beyond the five days) are allowed for running overtime (3 shifts a day).

APPENDIX II

DATA USED IN TABLE 1

Costs and Revenues

$\phi_{1,t}$ = \$170/-	$C_{1,t,1}$ = \$114.25
$\phi_{2,t}$ = \$195/-	$C_{1,t,2}$ = \$132.00
$\phi_{3,t}$ = \$150/-	$C_{2,t,1}$ = \$135.17
$\phi_{1,p,t}$ = \$0.68	$C_{2,t,2}$ = \$153.60
$\phi_{2,1,t}$ = \$0.67	$C_{3,t,1}$ = \$101.40
$\phi_{2,2,t}$ = \$0.65	$C_{3,t,2}$ = \$116.57
$\phi_{2,3,t}$ = \$0.69	$C'_{1,t,1}$ = \$127.96
$h_{1,t}$ = \$10.29	$C'_{1,t,2}$ = \$147.80
$h_{2,t}$ = \$12,87	$C'_{2,t,1}$ = \$151,40
$h_{3,t}$ = \$8.42	$C'_{2,t,2}$ = \$172.00
$h_{1,2,p,t}$ = \$0.035	$C'_{3,t,1}$ = \$113.60
$h_{2,2,1,t}$ = \$0.037	$C'_{3,t,2}$ = \$130.50
$h_{2,2,2,t}$ = \$0.036	$C_{1,p,t,1}$ = \$0.35
$h_{2,2,3,t}$ = \$0.038	$C_{1,p,t,2}$ = \$0.52
	$C_{2,1,t,1}$ = \$0.16
	$C_{2,1,t,2}$ = \$0.24
	$C_{2,2,t,1}$ = \$0.154
	$C_{2,2,t,2}$ = \$0.23
	$C_{2,3,t,1}$ = \$0.175
	$C_{2,3,t,2}$ = \$0.263

For all p,t

Data Concerning Resources Limitations

For all t

M_t = 3456000 hrs.

M'_t = 1248000 hrs.

L_t = 30720 hrs.

L'_t = 12480 hrs.

MY_t = 154828800 hrs.

MY'_t = 62899200 hrs.

LY_t = 40960 hrs.

LY'_t = 17640 hrs.

Initial Inventories

$I_{1,0}$ = 10000.00

$I_{2,0}$ = 5400.00

$I_{3,0}$ = 4000.00

$I_{1,2,1,0}$ = 1366800.00

$I_{2,2,1,0}$ = 1022400.00

$I_{1,2,2,0}$ = 1095200.00

$I_{2,2,2,0}$ = 795200.00

$I_{1,2,3,0}$ = 428800.00

$I_{2,2,3,0}$ = 265600.00

I_1 = 7500000

I_2 = 7000000

Sales Limits

$F'_{1,1} = 8000$	$F_{1,1} = 18500$
$F'_{2,1} = 4500$	$F_{2,1} = 11000$
$F'_{3,1} = 2800$	$F_{3,1} = 11500$
$F'_{1,2} = 9000$	$F_{1,2} = 17500$
$F'_{2,2} = 6500$	$F_{2,2} = 14000$
$F'_{3,2} = 5800$	$F_{3,2} = 13500$

$F_{i,p,t} = 10,000$ For all i,p,t

APPENDIX III

MODIFICATIONS TO THE FLEX PROGRAM

The production planning model was solved using the "Flex" program (for linear programming models) in the School of Industrial Engineering Library. Some changes in the dimensions of the array size were made to increase the size of the models that could be solved. There was an error in the original program which had to be corrected before the model could be solved.

In the original program, the restriction on the size of the models that can be solved is that maximum number of columns (variables) allowed is twice the maximum number of rows (constraints). The parameter MROW (maximum number of rows) can be set at any desired value. In the case solved, there were 58 constraints and 84 decision variables; which makes a matrix of size (58 x 142) including the slack and artifical variables. Setting the parameter MROW at 75 should have solved the model. Instead there was an error message, "Too many rows or columns." This result was caused by a mistake in the subroutine "LINUP" of the main program. In the computation for nonbasic activities, there are two do loops. In statement 271, a do loop parameter KK is compared with MROW and if KK is greater, the error message is printed out (where KK = NOROW + K, k is a counter and NOROW is the number of constraints). In the computation K takes a value equal to the number of activities bounded below. Now, if we set MROW at 75; that makes

MCOL (maximum number of columns) equal to 150. Since there were 58 constraints and 84 activities (decision variables) in the model solved, the total number of variables (including slack and artificial came to 142. (There were no surplus variables, as there were no greater than type constraints; activities bounded below were entered separately and were not included in the constraints.) As all the activities were bounded below, the do loop parameter KK took the value of (58 + 84) = 142 (since NOROW = 58, and K = 84). On comparing KK with MROW, KK was greater and hence the error message was given out. Instead of comparing KK with MROW, it should be compared with MCOL, because KK will always be greater than NOROW, and if NOROW = MROW then the program can never work. On correcting the error, the solution to the model was obtained.

The Flex program, which uses the standard simplex procedure, took on average 57 iterations to solve the model using 20,000 m.l. seconds of C.P.U. time on the Univac-1108 system.

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